Multipath Routing in Ad Hoc Wireless Networks with Omni Directional and Directional Antenna: A Comparative Study

Siuli Roy[*], Somprakash Bandyopadhyay[*], Tetsuro Ueda[+], Kazuo Hasuike[+]

[*] Indian Institute of Management Calcutta, Joka, Calcutta 700104, India
[+] ATR Adaptive Communications Research Laboratories, Kyoto 619-0288, Japan
{siuli, somprakash}@iimcal.ac.in, {teueda, hasuike}@atr.co.jp

Abstract. Several routing schemes have been proposed in the context of mobile ad hoc network. Some of them use multiple paths simultaneously by splitting the information among multitude of paths, as it may help to reduce end-to-end delay and perform load balancing. Multipath routing also diminishes the effects of unreliable wireless links in the constantly changing topology of ad hoc networks to a large extent. *Route coupling*, caused by the interference during the simultaneous communication through multiple paths between a pair of source and destination, severely limits the performance gained by multipath routing. Using *node disjoint* multiple paths to avoid coupling is not at all sufficient to improve the routing performance in this context. Route coupling may be reduced to a great extent if zone disjoint or even partially *zone disjoint* paths are used for data communication. Two paths are said to be *zone disjoint* if data communication through one path does not interfere with other paths. Large path length (number of hops) also contributes to the performance degradation resulting in high end to end delay. So zone disjoint shortest multipath is the best choice under high traffic condition. However, it is difficult to get zone disjoint or even partially zone disjoint multiple routes using omni-directional antenna. This difficulty may be overcome if directional antenna is used with each mobile node. In this paper, we have done a comparative study on the performance of multipath routing using omni-directional and directional antenna. The result of the simulation study clearly shows that directional antenna improves the performance of multipath routing significantly as compared to that with omni-directional antenna.

1 Introduction

The routing schemes for ad hoc networks usually employ single-path routing [1,2]. Multipath routing scheme employs a set of paths from source S to destination D so that total volume of traffic may be divided and communicated via selected multiple paths which would perform load balancing and eventually reduce congestion and end to end delay [3-10]. It also diminishes the effect of unreliable wireless links in the constantly changing topology of mobile ad hoc network [6]. Moreover, the frequency of route discovery is much lower if a node maintains multiple paths to destination. However, r*oute coupling*, caused by the interference during simultaneous communication through multiple paths, severely limits the performance gained by multipath routing in the context of ad hoc wireless networks. Using node disjoint multipath is not sufficient to improve the routing performance, as this inherent route coupling among those multiple paths may cause congestion. In order to reduce route coupling, directional antenna may be used instead of omni directional antenna. Due to low transmission zone of directional antenna, it is easier to get two physically close paths that may not interfere with each other during data communication. As a result, multipath routing performance will improve with directional antenna as compared to that with omni-directional antenna. To illustrate this point, the remainder of the paper is organized as follows: section 2 reviews related work. In section 3, notion of route coupling and zone disjoint routes is introduced. Section 4 and 5 present an analysis of multipath routing using omni-directional and directional antenna respectively. Section 6 presents a comparative analysis with performance results followed by concluding remarks in section 7.

2 Related Work

Application of multipath routing in ad hoc wireless network has been explored in recent years. An On Demand Multipath Routing scheme is presented in [7] as an extension of DSR [8] which uses one of the alternate routes kept in the source node for data communication if primary one fails. The Split Multipath Routing (SMR) proposed in [10] focuses on using maximally disjoint paths. It was argued in [9] that the performance of Alternate Path Routing depends a great deal on network topology and channel characteristics (Route Coupling). Two node disjoint paths are said to be coupled with each other if they are located physically close enough to interfere with each other during data communication. As a result, nodes on those paths, which are participating in simultaneous active communications, are constantly contending to access the medium and finally end up performing worse than single path protocol. Performance improvement in multipath routing through load balancing is studied in [9] but their work is based on multiple channels that are contention-free but may not be available in normal cases. Selection of node disjoint paths to improve the performance is discussed in [10, 11, 12]. But inherent route coupling degraded the performance gained by using node disjoint multiple paths [9]. So it is intuitive that route coupling should be reduced to achieve good routing performance. The effect of route coupling can be drastically reduced, if we use directional antenna instead of omni-directional antenna with each user-terminal forming an ad hoc network. It has been shown that the use of directional antenna can largely reduce radio interference, thereby improving the utilization of wireless medium and consequently the network throughput [13, 14]. In our earlier work, we have developed the MAC and routing protocol using directional ESPAR antenna [13, 15] and demonstrated the performance improvement. In this paper, we investigate the effect of directional antenna on multipath routing. We have done a comparative study on the performance of multipath routing using omni-directional and directional antenna. The result of the simulation study clearly shows that directional antenna improves the performance of multipath routing significantly as compared to that with omni-directional antenna.

3 Effect of Route coupling

Suppose there are two node-disjoint paths, S1-x1-y1-D1 and S2-x2-y2-D2, ie. they share no common nodes. Since paths are node-disjoint, it is expected that the end to end delay in each case should be independent of each other. However if x1 and x2 and/or y1 and y2 are neighbors of each other, then two communications can not happen simultaneously because the RTS/CTS exchange during data communication will allow either x1 or x2 to transmit data packet at a time and so on. So end to end delay does not depend only on the congestion characteristics of the nodes, pattern of communication in the neighborhood region also contributes to this delay. This phenomenon is called *route coupling*. As a result, coupled nodes in those two paths are constantly contending to access the medium thereby degrading the performance of multipath protocol. Thus node-disjoint paths are not at all sufficient for improved performance. So we proposed a notion of *zone-disjoint* paths for simultaneous data communication to improve network performance. Two paths are said to be zone disjoint if data communication through one path does not interfere with other paths. But getting zone-disjoint or even partially zone disjoint paths using omni directional antenna is difficult since transmission zone is larger. Transmission zone for each node in case of omni-directional antenna $=\pi R^2$ where beam angle $\theta = 360^\circ$ and transmission range is R. By controlling the beam angle θ ($<360°$) using directional antenna, coverage area of each node may be reduced to $\theta R^2/2$. So a node on a path (x1 on S1-x1-y1-D1), interfering the transmission along other path (S2-x2-y2-D2) due to coupling between x1 and x2 earlier using omni-directional antenna, may not interfere with each other during data communication if directional antenna is used. The effect of route coupling is measured in [12] using a correlation factor η and paths with lower correlation factors are selected for simultaneous communications. We have redefined correlation factor η of a node n in a path P, $\eta^n(P)$, as the number of *active neighbors* of n not belonging to path P, where *active neighbors* of n is defined as those nodes within the transmission zone of n that are actively participating in any communication process at that instant of time. Correlation factor η of path P, $\eta(P)$ is defined as the sum of correlation factor of all nodes in path P (figure 1). Path P is said to be zone disjoint if $\eta(P) = 0$. Paths with lowest $\eta(P)$ values are selected to obtain Zone disjoint / partially zone disjoint paths. But to consider the effect of path length in this context, longer paths with more number of hops are discarded, as they increase end to end delay. To deal with the problem, our route selection criteria is to minimize the product of η and H (=number of hops in path P).

4 Multipath Routing with Omni-Directional Antenna

It is difficult to get fully zone-disjoint routes using omni-directional antenna. As in figure 1, since both a and d are within omnidirectional transmission range of S, a RTS from S to node a will also disable node d. Similarly, since both c and f are within omni- directional transmission range of D, a CTS from D will disable both c and f. So, the lowest possible η [η^{min}(omni)] in case of omni-directional antenna with two

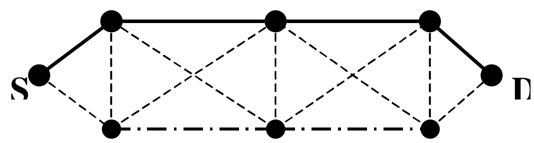

Fig 1. Two node disjoint paths with η=9

multipath between s and d is 2 if two paths have *no common nodes* excepting source and destination. With directional antenna, it is possible to de-couple these two routes, making them fully zone-disjoint. If each node sets their transmission zone towards its target node only, then the communication between S-a-b-c-D will not affect the communication between S-d-e-f-D. Hence η^{min}(omni)=2 whereas η^{min}(dir)=0.
As a result, even if we get multiple zone-disjoint routes with minimal correlation factor using omni-directional antenna, the best-case packet arrival rate at the destination node will be 1 packet at every $2*t_p$, where t_p is the average delay per hop per packet of a traffic stream on the path p. The best-case assumption is, single traffic stream in the network from S to D with error-free transmission of packets. Let us refer to figure 1 and assume that each node is equipped with omni-directional antenna and two paths having minimal correlation factor i.e. η = 2 are used for data communication. This implies that nodes{a,b,c} and nodes {d,e,f} are disjoint. Let us denote t_p as a time-tick, and at each time-tick, a packet is getting transmitted from one node to other. Consider table 1. S is sending a data-packet P_1 to node a at time-tick T_0 and node a is sending data-packet P_1 to node b in the next time tick i.e. T_1. With omni-directional antenna, S has to sit idle during T_1, because S has received RTS from node a. So, S can only transmit its second packet P_2 to node d (first node of the second path) at time-tick T_2. The packet transition is shown in Table 1 and destination D will receive packets in alternate time-tick. *Even if we increase the number of paths between s and d beyond 2, the situation will not improve with omni-directional antenna*.

Table 1. Packet arrival rate at D with omni-directional antenna with two paths (s-a-b-c-d and s-d-e-f-d) having minimun η (=2)

	S	a	b	c	d	e	f
T_0	P_1 >a						
T_1		P_1>b					
T_2	P_2>d		P_1>c				
T_3				**P_1>D**	P_2>e		
T_4	P_3>a					P_2>f	
T_5		P_3>b					**P_2>D**
T_6	P_4>d		P_3>c				
T_7	…	…	…	…	…	…	…

5 Multipath Routing with Directional Antenna

In contrast, if we use directional antenna, best-case packet arrival rate at destination will be one packet at every $t_{p.}$ Table 2 illustrate this point. With directional antenna, when node a is transmitting a packet to node b, S can transmit a packet to node d simultaneously. Thus, as shown in Table 2, destination D will receive a packet at every time-tick with two zone-disjoint paths using directional antenna. It is to be noted here that *two zone-disjoint paths with directional antenna is sufficient to achieve this best-case scenario.*

Table 2. Packet arrival rate at d with directional antenna with two zone-disjoint paths (s-a-b-c-d and s-d-e-f-d) having η=0.

	S	a	b	c	d	e	f
T_0	P_1 >a						
T_1	P_2>d	P_1>b					
T_2	P_3>a		P_1>c		P_2>e		
T_3	P_4>d	P_3>b		**P_1>D**		P_2>f	
T_4	P_5>a		P_3>c		P_4>e		**P_2>D**
T_5	P_6>d	P_5>b		**P_3>D**		P_4>f	
T_6	P_7>a		P_5>c		P_6>a		**P_4>D**

6 Effect of Directional and Omni Directional Antenna on Multiple Multipath Communications : A Comparative Study

In this study, nodes were randomly placed into an area 1000 X 1500 at a certain density. Sources and destinations were selected such that they are multi hop away from each other. A source and destination were randomly selected and multi-hop (maximum hop = 5) paths are found. Between the selected source and destination, two zone-disjoint routes were found out using fixed range directional antenna. If two zone-disjoint routes were not available for that source-destination pair, another source-destination pair was selected. Then we have assumed that each node is having omni-directional antenna and computed the correlation factor η_{omni} among those two routes that are zone-disjoint with directional antenna. This experiment was repeated for 25 source destination pair. As discussed, in each case, η_{dir} is zero and we compute η_{omni} . Then, the average η_{omni} were found out. Then, we change the node density and repeat this experiment. The results are shown in figure 2. As the number of nodes in the system increases, average η_{omni} increases. However, η_{dir} is zero in all the cases. This indicates that it is possible to get zone-disjoint paths with directional antenna at different node densities but same paths will have high correlation factors, if we use omni-directional antenna instead.

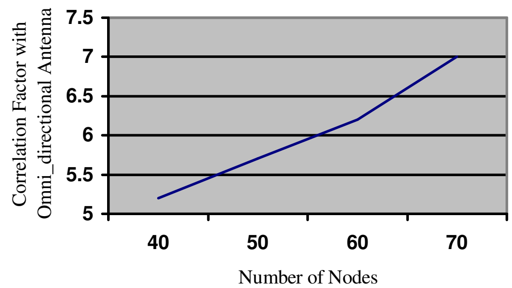

Fig. 2. Average correlation factor η_{omni} at different number of nodes when η_{dir} =0.

Effect of new coupling factor gamma (γ = η*H) on multiple multipath communications with directional and omni directional antenna is studied in the same simulation environment and it is found that, if the number of simultaneous communications increases in the network, the coupling factor γ increases substantially in case of omni directional antenna compared to directional antenna. Average gamma (γ) is calculated by taking two low γ paths for each of the active communications in the system. It is found that average gamma (γ) increases sharply using omni directional antenna if number of simultaneous communications in the system increases. On the other hand if each node is equipped with directional antenna with fixed transmission zone angle 60° then increase of average gamma for the system is not so high compared to omni directional case. Figure 3 clearly shows the above result.

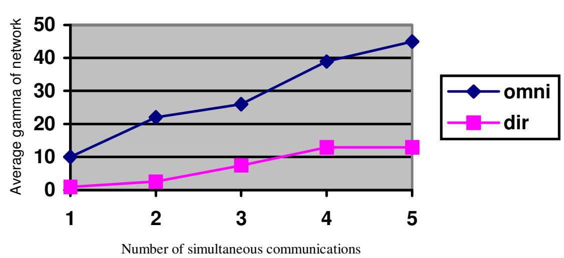

Fig. 3. Increase in route coupling with multiple multipath communications with omni directional and directional antenna

Average end to end delay per packet between a set of selected s-d pairs with increasing number of communication has been shown in figure 4. The result shows that the average end-to-end delay per packet increases much more sharply with omni-directional antenna compared to that with directional antenna. This is an obvious consequence of the phenomenon illustrated with figure 3 and it can be concluded that the routing performance using multiple paths improves substantially with directional antenna compared to that with omni-directional antenna.

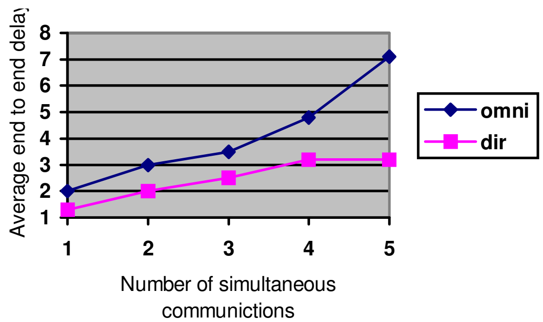

Fig 4. Increase in average end to end delay with multiple multipath communications using omni- and directional antenna : A sample observation

7 Conclusion

In order to make effective use of multipath routing protocols in the mobile ad hoc network environment, it is imperative that we consider the effects of route coupling. However, high degree of route coupling among multiple routes between any source and destination pair is inevitable, if we use omni-directional antenna. The situation will worsen, if we consider multiple simultaneous communications with multiple active routes. This paper has analysed the problem and proposed a mechanism to alleviate the problem of route coupling using directional antenna. As a result, the routing performance using multiple paths improves substantially with directional antenna compared to that with omni-directional antenna.

References

1. E. M. Royer and C-K Toh, “A Review of Current Routing Protocols for Ad hoc Wireless Networks”, IEEE Personal Communication, April 1999, pp. 46-55.
2. J. Broch, D. A. Maltz, D. B. Johnson, Y. C. Hu, and J. Jetcheva, "A Performance Comparison of Multi-Hop Wireless Ad Hoc Network Routing Protocols,' *Proc. ACM/IEEE Mobile Comput. and Network.*, Dallas, TX, Oct. 1998.
3. Sajal K. Das, A. Mukherjee, Somprakash Bandyopadhyay, Krishna Paul, D. Saha, “Improving Quality-of-Service in Ad hoc Wireless Networkswith Adaptive Multi-path Routing, Proc. Of the GLOBECOM 2000, San Francisco, California, Nov. 2000.
4. N.S.V.Rao and S.G. Batsell, QoS Routing via Multiple Paths Using Bandwidth Reservation, Proc. of the IEEE INFOCOM 98.

5. S. Bahk and W. El-Zarki, Dynamic Multi-path Routing and how it Compares with other Dynamic Routing Algorithms for High Speed Wide-area Networks, in Proc. of the ACM SIGCOM, 1992
6. Aristotelis Tsirigos Zygmunt J. Haas, Siamak S. Tabrizi , Multi-path Routing in mobile ad hoc networks or how to route in the presence of frequent topology changes , MILCOM 2001.
7. A. Nasipuri and S.R. Das, "On-Demand Multi-path Routing for Mobile Ad Hoc Networks," Proceedings of IEEE ICCCN'99, Boston, MA, Oct. 1999.
8. B. Johnson and D. A. Maltz, "Dynamic Source Routing in Ad Hoc Wireless Networks," T. Imielinski and H. Korth, editors, *Mobile Computing*, Kluwer, 1996.
9. M. R. Pearlman, Z. J. Haas, P. Sholander, and S. S. Tabrizi, On the Impact of Alternate Path Routing for Load Balancing in Mobile Ad Hoc Networks, MobiHOC 2000.
10. S.J. Lee and M. Gerla, Split Multi-path Routing with Maximally Disjoint Paths in Ad Hoc Networks, ICC 2001.
11. Z. J. Haas and M. R. Pearlman, "Improving the Performance of Query-Based Routing Protocols Through Diversity Injection," *IEEE Wireless Communications and Networking Conference WCNC 1999,* New Orleans, LA, September 1999.
12. Kui Wu and Janelle Harms, On-Demand Multipath Routing for Mobile Ad Hoc Networks EPMCC 2001, Vienna, 20th – 22nd February 2001
13. Somprakash Bandyopadhyay, K. Hasuike, S. Horisawa, S. Tawara, "An Adaptive MAC Protocol for Wireless Ad Hoc Community Network (WACNet) Using Electronically Steerable Passive Array Radiator Antenna", Proc of the GLOBECOM 2001, November 25-29, 2001, San Antonio, Texas, USA
14. Y.-B. Ko, V. Shankarkumar and N. H. Vaidya, ``Medium access control protocols using directional antennas in ad hoc networks," Proc. Of the IEEE INFOCOM 2000, March 2000.
15. Somprakash Bandyopadhyay, K. Hasuike, S. Horisawa, S. Tawara, "An Adaptive MAC and Directional Routing Protocol for Ad Hoc Wireless Network Using Directional ESPAR Antenna" Proc of the ACM Symposium on Mobile Ad Hoc Networking & Computing 2001 (MOBIHOC 2001), Long Beach, California, USA, 4-5 October 2001.